Acoustic Characterization of Mesoscale Objects

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Mesoscience is an emerging area of science and engineering that focuses on the study of materials with dimensions, features, and structures that range from a few millimeters down to a few micrometers. Mesoscale objects typically have embedded features that require characterization with resolution on the order of a few micrometers. Mesoscale nondestructive characterization technologies are required that can 1) penetrate into or through a few millimeters of diverse materials; and 2) provide spatial resolutions of about a micrometer.

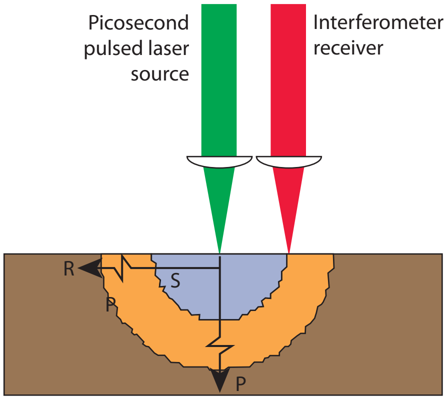
An acoustic technique is attractive because it offers high sensitivity to features such as thickness and interface quality that are important to mesoscale objects. In addition to the resolution requirements, many mesoscale objects require a non-contact technique to avoid damaging fragile surfaces.

Project Goals

This research will achieve micrometer resolution characterization by extending the range of laser-acoustic testing to GHz frequencies. Materials and the geometry of components used in most LLNL mesoscale objects necessitate the use of a non-contacting technique at frequencies from 100 MHz to 10 GHz. This frequency range is required to acoustically characterize features from 5 to 0.5 µm in size. In order to be applicable to mesoscale objects, the GHz acoustic waves must propagate sufficient distances into materials of interest. For LLNL applications, mesoscale structures are on the order of 25 to 200 µm thick.

Relevance to LLNL Mission

This work directly addresses metrology and characterization gaps of interest in LLNL's engineering focus areas, such as measurement technologies and nondestructive characterization. Of the different mesoscale characterization challenges at LLNL, the targets prepared



Surface (R), Shear (S), and longitudinal (P) waves generated

Figure 1. Schematic of laser ultrasound technology. Laser UT uses a pulsed laser as a source to generate acoustic waves and a laser interferometer to detect acoustic waves. The source and receiver can be on the same side (as shown) or on opposite sides of the object. The acoustic wave travels through the object before it is detected. Use of a pulsed laser gives temporal resolution to the detected signal.

for OMEGA and NIF are the most relevant. This proposal impacts the DNT, NIF, Engineering, and Chemistry and Materials Science Directorates through target fabrication and characterization.

FY2006 Accomplishments and Results

The primary research goal in the final year of this project is to understand GHz acoustic wave propagation and its potential for material characterization. Two major accomplishments in support of this goal are validation of laser-acoustic models with experimental data, and identification and validation of material attenuation modes in relation to material microstructure.

Theoretical and experimental waveforms for a 25-µm-thick gold foil taken with the configuration in Fig. 1 are shown in Fig. 2. The analytical model, which includes laser and material parameters, shows good agreement with measured data. Figure 3 shows the frequency dependence of the acoustic-wave attenuation in the gold foil. The quadratic relation to attenuation is characteristic of stochastic grain scattering where wavelength, λ, is proportional to the grain size. At 0.8 GHz in gold, $\lambda = 4$ µm. From micrographs of the gold, the grain size was confirmed to be approximately 4 µm. This finding demonstrates that GHz laser ultrasound can be a valuable tool in material characterization.

Related References

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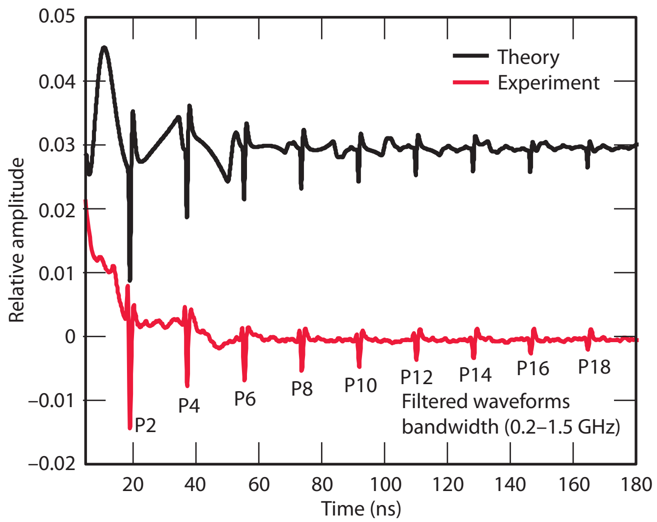

Figure 2. Using the configuration in Fig. 1, temporal signals from modeled (black) and measured (red) signals for a 25-µm-thick gold foil, show good correlation. Each peak in the signal represents an arrival of an acoustic wave at the epicentral location. The analytical model includes laser energy, spot size, and pulse width as well as optical, thermal, and mechanical properties of the material.

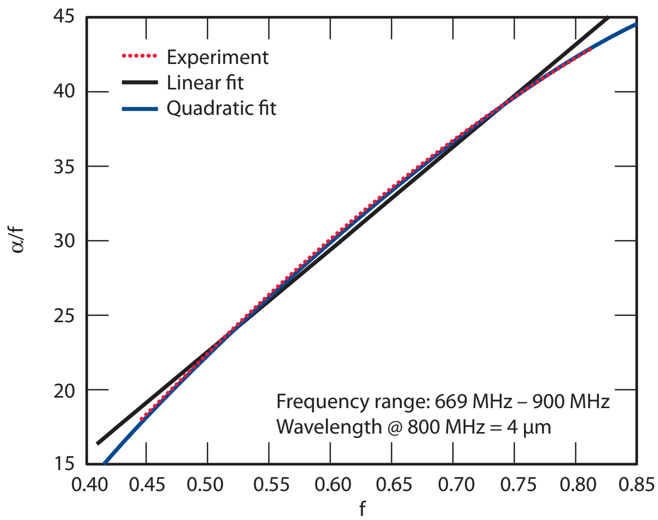

Figure 3. Frequency dependence of the acoustic-wave attenuation in the 25-µm gold foil. Acoustic attenuation of the wave propagation increases with the square of the frequency. This dependence is characteristic of stochastic grain scattering.